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The effects of water deficit and polymer on some physiological traits in corn (*Zea mays* L.)

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ABSTRACT

Drought stress is the most important problem of agriculture in the wide world arid and semiarid areas. The application of some material such as superabsorbent polymers in soil could increase water retention in soil and decrease leaching of water and fertilizer. This experiment was conducted on corn (Zea mays L.) in Dashtak, Zahedan during growing 2012-2013. The experiment was carried out as split-plot with two factors including three irrigation regimes including irrigated with 60%, 80% and 100% crop evapotranspiration (ET_c) respectively as main plots and four amounts of superabsorbent polymer (SAP) including 0, 30, 60 and 90 kg ha^{-1} as subplots in a completely randomized block design with three replications. The results showed that the effect of irrigation regimes, SAP levels and interaction between two factors had significant effect on all traits. The regression models estimated for relative water content (RWC), chlorophyll index (CI), remobilization of photosynthetic matters (RPM), portion of remobilization to seed and seed yield showed that applying SAP in 100% ET_c treatment had no different effect on above traits, but in the treatments which were exposed with water deficit improved all the traits of corn. The results also showed that applying 60 kg ha^{-1} SAP decreased corn's water requirement as much as 20% and caused a seed yield and physiological characters equivalent to the 100% irrigation treatment.

Keywords: Irrigation regime, physiological characters, superabsorbent polymer.

INTRODUCTION

Drought is one of the most important factors that limit plant growth in arid and semi arid areas like Iran. Applying accurate managements and advanced techniques with the aim of improving soil water capacity is of the effective procedures to increase irrigation efficiency, leading to enhance utilization of the limited-water resources of the country. These aims could be achieved via doing some proceedings such as the use of green manures and organic fertilizers, artificial and plant mulch, development of vegetation and or applying ameliorative materials like peat, perlit and polymers [1]. Corn is a C_4 plant which consumes 368 liter of water to produce one gram of dry matter [2]. Drought stress occurrence at vegetative and reproductive stages in the world's tropical areas causes around 17 and 30 per cent reduction, respectively, in corn yield [3]. Polymers can reduce negative effects of drought on corn and enhance its yield, so they can decrease amount of required water to produce dry matter in corn [4,5]. Superabsorbent polymers are made of hydrocarbon. These materials absorb water several times more that their weight and lose it gradually, due to environment in dry conditions [6,7]. Thus, soil remains moist for a long time without renewed-irrigation requirement [8,9]. The quantity of absorbed water in these polymers is depended on their chemical formula, impurity and salt of the water and it varies to 400 times of the polymer weight [10,11].

Superabsorbent polymers bring improvement in soil water retention and reduce the irrigation quantity by 50% [12]. Given aforementioned reasons, the significance of these materials is expanding in arid areas. Polymers are environmentally clean and do not have any poisonous and deleterious impacts on soil. They finally decompose to Co_2, water and Ammonium and Potassium ions [13,14]. Superabsorbent can cause improvement in physical traits of soil, prevention from soil erosion and nutrient leaching and they also enhance quality of gravity water [15].

Reduction of leaf relative water content (RWC), increase of stomatal resistance and photosynthesis decline are among physiological effects of water stress. Through decease in soil water content and afterwards RWC, stomata conductance reduces and Co_2 availability would be restricted and as a consequence, corn photosynthesis declines [16]. There is a positive correlation between leaf relative water content and leaf area expansion [17] in the way that leaf area index reduces under water stress conditions [7] and this is followed by photosynthesis diminish [18]. On the other hand water deficit causes chlorophyll content reduction, leaf senescence and therefore reduction in leaf area duration and increase Nitrogen remobilization from leaves. Affected by all these factors, photosynthesis rate would reduce [19].

Corn plant prevents from intensive yield reduction via increase in dry matter remobilization when encounters with water stress. Factors such as genotype, plant density and water stress intensity are influential factors on potential of remobilization which is a desirable physiological feature [20]. Under water stress, current photosynthesis decreases at grain filling stage and plant uses stored matters in leaves and steam to meet grain need and for this reason, compared to intensive and moderate stress, the amount of remobilization is less in normal irrigation treatmen. Several events such as: rise of ABA/Cytokinin proportion in leaves, leaf area reduction, increase in plant tissues death, leaves abscission in downside of plant, increase in respiration rate due to shading and light interception have been reported at grain filling stage of corn [21]. It is showed that remobilization of photosynthesis matters (RPM) and portion of remobilization in grain yield are significantly influenced by drought water stress and its rate in average reached to a high of 164.42g.m^{-2} under moderate water stress treatment [20]. The objectives of this investigation were to determine the effects of Superab A200 and irrigation regime on leaf relative water content, chlorophyll index, rate of remobilization of photosynthesis matter and its portion in grain yield.

MATERIALS AND METHODS

This study was carried out in Dashtak south west of Iran (25° 30´N and 58°30´W) with rainfall average of 120 mm and hot and dry climate in two years 2012 and 2013. The experiment was carried out as split-plot with two factors consisted of three irrigation regimes including irrigated with 60%, 80% and 100% crop evapotranspiration (ET_c) respectively as main plots and four amounts of superabsorbent polymer (SAP) including 0, 30, 60 and 90 kg ha^{-1} as subplots based on a completely randomized block design with three replications. In each year sowing date was April 4. Each plot was planted using around 7 plants per m^{-2} as planting rate and comprised of 6 rows, 70 cm apart between rows, 12 cm apart in rows and 6.5 m long. Before sowing, superabsorbent was applied next to the rows under seedbed in depth of 15-20 cm (maximum of root density). The soil amendment used was a hydrophilic polymer, SAP produced by Rahab Resin Co. Ltd., under license of "Iran Polymer and Petrochemical Institute". The chemical structure of SAP is shown in Table 2 [22-24].

Table 2. The properties of Superab A200 Polymer

Appearance	White granule
Grain size (mm)	0.5-1.5
Water content (%)	3-5
Density (g cm-3)	1.4-1.5
pH	6-7
The actual capacity of absorbing the solution of 0.9 % NaCl	45
The actual capacity of absorbing tap water	190
The actual capacity of absorbing distilled water	220
Maximum durability (year)	7

Water requirements were determined according to FAO method and using the evaporation pan data on base American A-class [25,26]. Daily evaporation and pan coefficient was calculated as follows:

$$Et_c = K_c \times ET_c \qquad [1]$$

ETc: Maize evapotranspiration
Kc: crop coefficients
ETo: evapotranspiration of the reference crop
Crop coefficient was calculated using equation (2):

$$K_c = \frac{ET_a}{ET_p} \quad [2]$$

Where ET_a and ET_p are real and critical evapotranspiration, respectively (Howell et a., 2008).
Reference crop evapotranspiration (ET_o) obtained using equation (3):

$$ET_o = K_{pan} \times E_p \quad [3]$$

At the end of the season, to assess yield, considering margin effect, corns of one square meter were harvested. To measure dry matter of stem, leaf and grain, samples were kept under 70-75 centigrade degree until reaching a constant weight then were weighed by a digital scale.

The amount of remobilization of photosynthetic matters and its portion in gain yield were calculated using equation (4) and (5) (20).

$$RPM = VDW_{silking} - VDW_{maturity} \quad [4]$$

Where RPM is amount of remobilization (g.m^{-2}) and $VDW_{silking}$ and $VDW_{maturity}$ are dry weight (g.m^{-2}) of vegetative organs at silking and maturity stage.

$$PRSY = \frac{RPM}{GY} \times 100 \quad [5]$$

Where GY and $PRSY$ are grain yield (g.m^{-2}) the portion of remobilization in grain yield, respectively.
Leaf RWC: this parameter was measured at flowering a day before irrigation round between 8 and 9 am o'clock in three plants from each plot. After weighing fresh samples (FW) to obtain turgor weight (TW) they were embedded in distilled water for 24 hours and were weighed, then were dried at 70 centigrade degree temperature for 24 hours to calculate dry weight (DW). Leaf RWC was calculated using equation (6) [27]. 2005).

$$RWC = \frac{FW - DW}{TW - DW} \quad [6]$$

Chlorophyll Index (CI): this index was measured using SPAD-502 (made by KONICA MINOLTA) from three: proximal, middle and distal parts of ear leaf of three plants from each plot. Finally for each plot one number as average was employed in calculations.

Statistical analysis was performed using SAS software for a split plot arranged in a randomized complete block design. Year was considered as a random effect in the statistical analysis. For every variable ANOVA was conducted using GLM procedure and probability levels related to simple, linear, quadratic, cubic and interaction effects have been shown as ANOVA table. The Linear, quadratic, and cubic models were tested for irrigation regime and SAP level. The regression equations were fitted by PROC REG. The linear, quadratic, and cubic regression models were tested for each irrigation level, with SAP level entered in the model as an independent variable. All the estimated parameters in the regression models were significant at $P < 0.01$.

Table 1. The properties of Superabsorbent A200 material

Appearance	White granule
Grain size (mm)	0.5-1.5
Water content (%)	3-5
Density (g cm^{-3})	1.4-1.5
pH	6-7
The actual capacity of absorbing the solution of 0.9 % NaCl	45
The actual capacity of absorbing tap water	190
The actual capacity of absorbing distilled water	220
Maximum durability (year)	7

RESULTS AND DISCUSSION

Relative water content

Irrigation and superabsorbent treatments had significant effects on leaf RWC and its response to irrigation and superabsorbent was linear and quadratic, respectively (table 2). Also interaction effect of irrigation and superabsorbent on leaf RWC was significant ($P \leq 0.001$). Calculated regression equation for each irrigation level showed that:

1. Response of leaf RWC to superabsorbent under the treatment 60% evaporation from pan followed a linear function which accounted for 97% of leaf RWC changes. Accordingly, under 60% evaporation from pan, the least (49.6%) and the highest (63.1%) of leaf RWC was observed by applying 0 and 90 kgha^{-1} superabsorbent, respectively (table 3).
2. Response of leaf RWC to superabsorbent under the treatment 80% evaporation from pan followed a linear function which accounted for 98% of leaf RWC changes. Accordingly, under 80% evaporation from pan, the least (57.5%) and the highest (64.7%) of leaf RWC was observed by applying 0 and 90 kgha^{-1} superabsorbent, respectively (table 3).
3. Response of leaf RWC to superabsorbent under the treatment 100% evaporation from pan was non-significant showing that superabsorbent application under optimum irrigation conditions had no efficiency (table 3). Leaf RWC reduced as irrigation quantity decreased and it increased in parallel with the amount of superabsorbent (Fig. 1). Due to reduction in the amount of irrigation, leaf RWC reduces [25]. By increasing in the amount of superabsorbent in soil, amount of leaf RWC rises [28].

Chlorophyll Index

Irrigation and superabsorbent treatments had significant effects on chlorophyll index and its response to irrigation and superabsorbent was linear (table 2). Also interaction effect of irrigation and superabsorbent on chlorophyll index was significant ($P \leq 0.005$). Calculated regression equation for each irrigation level showed that:

1. Response of chlorophyll index to superabsorbent under the treatment 60% evaporation from pan followed a quadratic function which accounted for 98% of chlorophyll index changes. Accordingly, under 60% evaporation from pan, the least (19.4) and the highest (25.07) of chlorophyll index was observed by applying 0 and 90 kgha^{-1} superabsorbent, respectively (table 3).
2. Response of chlorophyll index to superabsorbent under the treatment 80% evaporation from pan followed a linear function which accounted for 99% of chlorophyll index changes. Accordingly, under 80% evaporation from pan, the least (23.3) and the highest (29.6) of chlorophyll index was observed by applying 0 and 90 kgha^{-1} superabsorbent, respectively (table 3).
3. Response of chlorophyll index to superabsorbent under the treatment 100% evaporation from pan was non-significant showing that superabsorbent application under optimum irrigation conditions had no efficiency (table 3). Chlorophyll index reduced as irrigation quantity decreased and it increased in parallel with the amount of superabsorbent (Fig. 2). Under moderate and intensive water stress chlorophyll index quantity reduced by 100% [29]. Also it has been observed that chlorophyll index increases significantly in parallel with superabsorbent increment in soil [30].

Table 2. Probability level and degree of freedom for the effects of irrigation regime and superabsorbent A200 polymer on . relative water content, chlorophyll index (CI), remobilization of photosynthetic matters (RPM), (RWC), portion of remobilization in seed yield (PRSY) and seed yield in corn

		Probability Level				
S.O.V	df	RWC (%)	SPAD	RPM (g. m^{-2})	RSYP	SY (g. m^{-2})
Block	2	0.5	0.4	0.9	0.9	0.6
Irrigation	2	0.01	0.03	0.0004	0.0004	0.0002
Linear (L)	1	0.004	0.02	0.006	0.0003	0.0001
Quadratic (Q)	1	0.4	4	0.0002	0.002	0.02
Polymer	3	0.0001	0.0001	0.0001	0.0001	0.0001
Linear (L)	1	0.0001	0.005	0.0001	0.0001	0.0001
Quadratic (Q)	1	0.8	0.98	0.7	0.66	0.41
Cubic (C)	1	0.81	0.4	0.8	0.7	0.1
Irrigation × Polymer	6	0.001	0.005	0.0001	0.0001	0.0001
CV%		6.4	8.8	9.7	6.05	10.3

Remobilization of photosynthetic matters (RPM)

Irrigation and superabsorbent treatments had significant effects on remobilization of photosynthetic matters and its response to irrigation and superabsorbent was linear and quadratic, respectively (table 2). Also interaction effect of irrigation and superabsorbent on chlorophyll index was significant ($P \leq 0.0001$). Calculated regression equation for each irrigation level showed that:

1. Response of remobilization of photosynthetic matters to superabsorbent under the treatment 60% evaporation from pan followed a linear function which accounted for 99% of remobilization of photosynthetic matters changes. Accordingly, under 60% evaporation from pan, the highest (127.4 $g.m^{-2}$) and the least (103.1 $g.m^{-2}$) of remobilization of photosynthetic matters was observed by applying 0 and 90 $kgha^{-1}$ superabsorbent, respectively (table 3).

2. Response of remobilization of photosynthetic matters to superabsorbent under the treatment 80% evaporation from pan followed a quadratic function which accounted for 99% of remobilization of photosynthetic matters changes. Accordingly, under 80% evaporation from pan, the highest (167.4 $g.m^{-2}$) and the least (137.7 $g.m^{-2}$) of remobilization of photosynthetic matters was observed by applying 0 and 90 $kgha^{-1}$ superabsorbent, respectively (table 3).

3. Response of remobilization of photosynthetic matters to superabsorbent under the treatment 100% evaporation from pan was non-significant showing that superabsorbent application under optimum irrigation conditions had no efficiency (table 3). Remobilization of photosynthetic matters increased as irrigation quantity decreased and it reduced as the amount of superabsorbent in soil increased (Fig. 3). Presumably considering that drought stress reduces leaf area index and CGR, therefore current photosynthesis at grain filling stage decreases and plant uses stored matters in leaves and steam to meet grain need [20]. Under optimum irrigation conditions and nutrient elements availability increase in current photosynthesis via reduce in leaf senescence leads to reduction in photosynthesis assimilate remobilization [31].

The portion of remobilization of photosynthetic matters in grain yield

Irrigation and superabsorbent treatments had significant effects on the portion of remobilization of photosynthetic matters in grain yield and its response was linear and quadratic to irrigation and linear to superabsorbent (table 2). Also interaction effect of irrigation and superabsorbent on the portion of remobilization of photosynthetic matters in grain yield was significant ($P \leq 0.0001$). Calculated regression equation for each irrigation level showed that:

1. Response of the portion of remobilization of photosynthetic matters in grain yield to superabsorbent under the treatment 60% evaporation from pan followed a linear function which accounted for 99% of the portion of remobilization of photosynthetic matters in grain yield changes. Accordingly, under 60% evaporation from pan, the highest (34.3%) and the least (24.4%) of the portion of remobilization of photosynthetic matters in grain yield was observed by applying 0 and 90 $kgha^{-1}$ superabsorbent, respectively (table 4).

2. Response of the portion of remobilization of photosynthetic matters in grain yield to superabsorbent under the treatment 80% evaporation from pan followed a linear function which accounted for 99% of the portion of remobilization of photosynthetic matters in grain yield changes. Accordingly, under 80% evaporation from pan, the highest (34.06%) and the least (18.76%) of the portion of remobilization of photosynthetic matters in grain yield was observed by applying 0 and 90 $kgha^{-1}$ superabsorbent, respectively (table 4).

3. Response of the portion of remobilization of photosynthetic matters in grain yield to superabsorbent under the treatment 100% evaporation from pan was non-significant showing that superabsorbent application under optimum irrigation conditions had no efficiency (table 4). The portion of remobilization of photosynthetic matters in grain yield increased as irrigation quantity decreased and it reduced as the amount of superabsorbent in soil increased (Fig. 4). Remobilization of photosynthetic matters indicates portion of transferred to stored dry matter which increases affected by drought stress [31]. Given that dry matter transfers from both leaf and stem, so under drought stress remobilization from leaf increases caused reduction in leaf area duration an increase in portion of remobilization in grain yield due to photosynthesis decline at grain filling stage [31]. Also it would seems superabsorbent via improving effect on stem dry matter and current photosynthesis quantities can reduce the portion of photosynthesis matters remobilization in grain yield.

Table 3. Regression equations for the response of relative water content (RWC), chlorophyll index (SPAD) and remobilization of photosynthetic matters (RPM) to superabsorbent A200 polymer (SAP) for each irrigation level base on ETc (I).

I (ETc)	SAP (kg ha^{-1})	RWC (%)	SPAD	RPM (g m^{-2})
100	0 30 60 90	Model not significant	Model not significant	Model not significant
80	0 30 60 90	RWC=57.5+0.08SAP	SPAD=23.3+0.07SAP	PMR=167.4-0.33SAP
60	0 30 60 90	RWC=49.6+0.15SAP	SPAD =19.4+0.0007SAP^2	PMR=127.4-0.003SAP^2

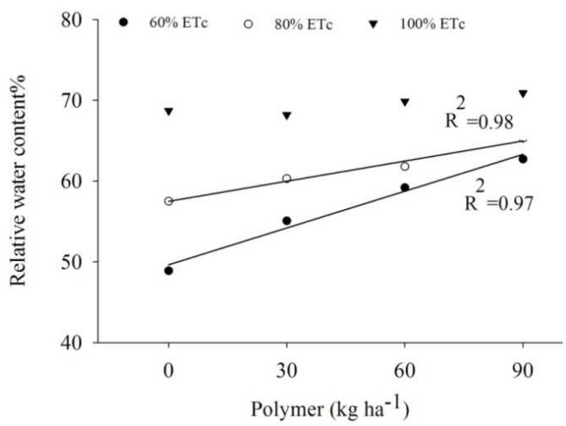

Figure 1. Predicted regression lines for relative water content (%) at 60 and 80% ETc with different SAP levels

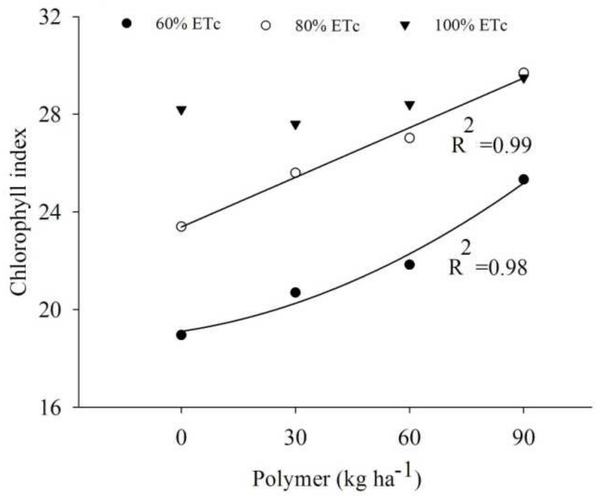

Figure 2. Predicted regression lines for chlorophyll index at 60 and 80 % ETc with different SAP levels.

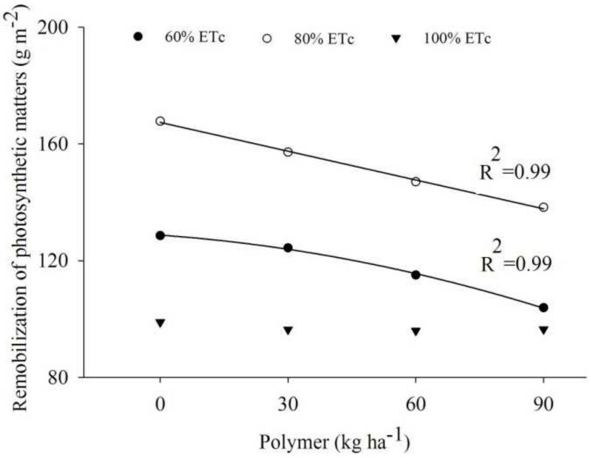

Figure 3. Predicted regression lines for remobilization of photosynthetic matters at 60 and 80 % ETc with different SAP levels.

Grain yield

Irrigation and superabsorbent treatments had significant effects on grain yield and its response was linear and quadratic to irrigation and linear to superabsorbent (table 2). Also interaction effect of irrigation and superabsorbent on the portion of remobilization of photosynthetic matters in grain yield was significant ($P \leq 0.0001$). Calculated regression equation for each irrigation level showed that:

1. Response of grain yield to superabsorbent under the treatment 60% evaporation from pan followed a linear function which accounted for 95% of grain yield changes. Accordingly, under 60% evaporation from pan, the least (378.7 g m^{-2}) and the highest (424.6 g m^{-2}) of grain yield was observed by applying 0 and 90 kgha^{-1} superabsorbent, respectively (table 4).

2. Response of grain yield to superabsorbent under the treatment 80% evaporation from pan followed a linear function which accounted for 94% of the portion of remobilization of photosynthetic matters in grain yield changes. Accordingly, under 80% evaporation from pan, the least (489.3 g m^{-2}) and the highest (723.3 g m^{-2}) of grain yield was observed by applying 0 and 90 kgha^{-1} superabsorbent, respectively (table 4).

3. Response of grain yield to superabsorbent under the treatment 100% evaporation from pan was non-significant showing that superabsorbent application under optimum irrigation conditions had no efficiency (table 4). Grain yield decreased as irrigation quantity reduced and it reduced in parallel with the amount of superabsorbent in soil (Fig. 5).

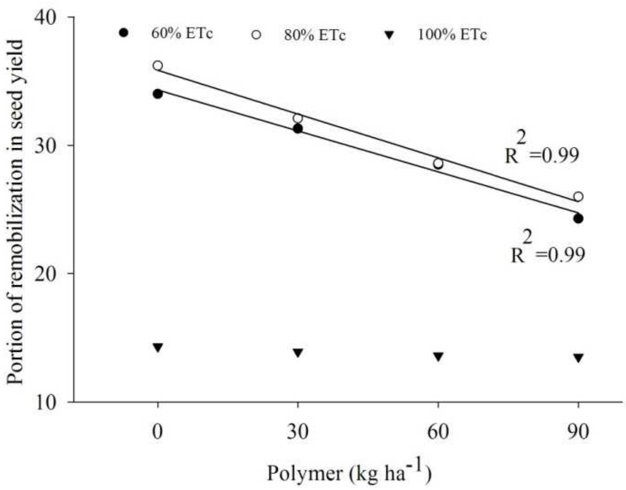

Figure 4. Predicted regression lines for portion of remobilization in seed yield at 60 and 80 % ETc with different SAP levels.

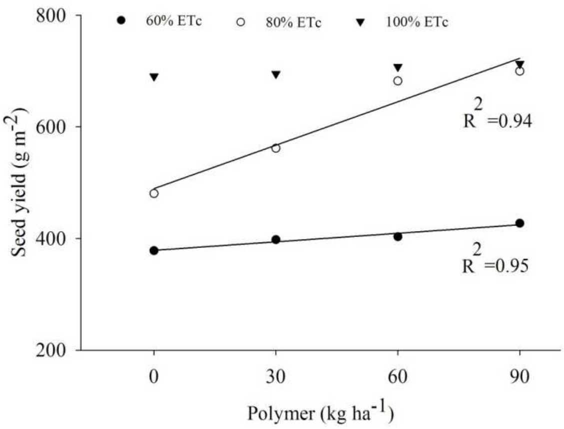

Figure 5. Predicted regression lines for seed yield at 60 and 80 % ETc with different SAP levels.

Water stress in the middle of grain filling period increases leaf senescence due to transporting nutrients from leaves [31]. Leaf area duration and dry matter accumulation after flowering stage have positive and significant correlation with grain yield so, through growth of photosynthesis activation at this stage, dry matter accumulation and grain yield rise [32]., 2010). By providing nutrient elements [4] superabsorbent can reduce chlorophyll degradation [22] and finally, it can lead to an increment in the duration of light use and plant photosynthesis. Increase in plant photosynthesis at grain filling period causes reduction in remobilization from leaves and increase in the duration of photosynthetic area which leads to a higher grain yield [29]. Enhanced Nitrogen transfer from leaves due to water stress causes chlorophyll content reduction [19].

DISCUSSION

Water stress reduced leaf RWC, chlorophyll index and grain yield. Reduction in leaf RWC leads to decrease in stomatal conductivity and Co_2 availability and finally the quantity of plant photosynthesis. The later results in lack of optimum leaf area development and dry matter accumulation per leaf area. Combination of these factors cause decrease in leaf area duration and net photosynthesis quantity at critical stage of grain filling, consequently increase in amount of assimilates remobilization at this period. In the present study, superabsorbent improved leaf RWC and chlorophyll index which led to a higher assimilate accumulation in vegetative organs and thus reduced the quantity and portion of assimilates remobilization in grain yield showed that application of 90 kg ha^{-1} superabsorbent cause 11 and 67.6 per cent increase in grain yield, respectively under levels 60% and 80% evaporation from pan. Application of 60 kg ha^{-1} superabsorbent caused 8 and 70.4 per cent increase in grain yield, respectively under levels 60% and 80%. However, it can be said that grain yield under optimum irrigation would be the same with what can be achieved by applying 60 kg ha^{-1} superabsorbent and reduction in irrigation by 20%.

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